

PATENT SPECIFICATION

(11) 1 396 828

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- (21) Application No. 18306/73 (22) Filed 16 April 1973
 (61) Patent of Addition to No. 1,364,274 dated 6 Aug. 1971
 (31) Convention Application No. 7 213 439
 (32) Filed 17 April 1972 in
 (33) France (FR)
 (44) Complete Specification published 4 June 1975
 (51) INT CL² G02F 1/13
 (52) Index at acceptance H4F 21C 23E 23M 25P1

(19)



(54) IMPROVEMENTS IN ELECTRO-OPTICAL MODULATIONS EMPLOYING CHROMATIC POLARIZATION

(71) We, THOMSON—CSF, a French Body Corporate, of 173, Boulevard Haussmann — 75008 Paris — France — do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This is an addition to the British Patent Application no 37 172/71 (Specification No. 1,364,274).

The present addition relates to optical devices which, under the action of an electrical control signal, are capable of modulating the intensity or colour of a light beam, by utilising an electro-optical effect.

The invention concerns a device in which the electro-optical effect employed is the variation in double-refraction of a thin film of an aligned nematic liquid crystal phase arranged between two parallel transparent plates and subjected to an electric field directed perpendicularly to the plane of the film. Such a film produces between its principal directions, a phase difference which is a function of the applied electric field; when illuminated with parallel monochromatic light, between cross-polarizers, it thus makes it possible to modulate the intensity of the transmitted light; in the same fashion, it makes it possible to modulate the colour of polychromatic radiation by varying the relative intensities of the different spectral components transmitted.

The present case relates more particularly to the case where the long parallel molecules constituting the nematic liquid crystal phase, are oriented, in the absence of any electric field, in a direction \vec{D} perpendicular to the plane of the plates.

This orientation of the liquid crystal molecules, although particularly attractive, since it produces a phase difference which is zero in the absence of any electric field and is a rising function of the applied electric field, can-

not be used in the modulator device described in Fig. 1 of the Parent Patent, as hereinafter explained.

The application of a uniform electric field parallel to \vec{D} simply determines the angle \hat{A} through which the molecules rotate, the axes of rotation of these latter being randomly distributed in a plane perpendicular to the field. The liquid crystal film, under these conditions, behaves as a double-refracting plate the difference in the refractive indices of which is uniform at all points, but whose principal directions vary randomly from one point to another. If such a plate, arranged between cross plane polarizers, receives parallel light, it is not effective since the intensity of the transmitted light, which depends upon the difference between the refractive indices and upon the orientation of the polarizers in relation to the principal directions of the film, varies depending upon the point in consideration.

In order to overcome this drawback, two solutions have been proposed in accordance with the present invention. The first solution consists in illuminating the film with circularly polarised light; the second makes it possible to give the assembly of molecules constituting the liquid crystal, an axis of rotation having a single direction, when the electric field is applied.

According to the present invention, there is provided an electrically controlled modulator as claimed in claim 1 of the Parent Patent Application No. 37 172/71 (Specification No. 1,364,274), wherein said molecular alignment is perpendicular to said plates, said control means comprising transparent electrodes arranged respectively upon the internal faces of said plates and said variable electric signal being a variable voltage applied between said electrodes; and further comprising first and second optical means for respectively transforming linearly polarized light into circularly polarized light and circularly polarized light

into linearly polarized light, said first and second optical means being arranged between said plane polarizers respectively at either side of said film.

According to the present invention, there is further provided an electrically controlled modulator as claimed in claim 1 of the Parent Patent Application No. 37 172/71 (Specification No. 1,364,274), wherein said molecular alignment is perpendicular to said plates, said control means comprising transparent electrodes arranged respectively upon the internal faces of said plates and said variable electric signal being a variable voltage applied between said electrodes; said film of a liquid crystal exhibiting a nematic phase is in contact with at least one surface containing parallel scratches, said scratches imposing, upon application of said variable voltage between said electrodes, a single direction to the rotation axis of said molecules.

According to the present invention, there is further provided an electrically controlled modulator as claimed in claim 1 of the Parent Patent Application No. 37 172/71 (Specification No. 1,364,274), wherein said molecular alignment is perpendicular to said plates, said control means comprising transparent electrodes arranged respectively upon the internal faces of said plates and said variable electric signal being a variable voltage applied between said electrodes; and further comprising electrical means for creating an additional electric field within the body of said film at least within the time interval during which said variable voltage is applied, said additional electric field being disposed parallel to the plane of said film.

For a better understanding of the invention and to show how the same may be carried into effect, reference will be made to the ensuing description and the following figures, among which:

Fig. 1 illustrates an example of the modified modulator device in accordance with the present invention;

Fig. 2 is an explanatory diagram dealing with the operation of the device in accordance with the present invention;

Fig. 3 illustrates a second example of a modification, in accordance with the present invention, to the modulator device;

Fig. 4 illustrates a third example of a modification, in accordance with the present invention, to the modulator device.

Fig. 1 illustrates an example of a modified version of a device shown in Fig. 1 of the parent patent, the subject of which modification is to make it possible to illuminate the liquid crystal film with circularly polarised light.

In this figure, a light source 1 can be seen, located at the point S upon an axis Oz, which source may either be a monochromatic radia-

tion source or a white light source (ordinary electric light bulb for example); this source is associated with a condenser 2 in order to produce a parallel beam having the axis Oz, which successively passes through a plane polarizer 3, a first quarterwave plate 30, the double-refracting cell comprising the thin film of liquid crystal 6 confined between the two parallel transparent plates 4 and 5, a second quarterwave plate 70, and a plane analyser 7 arranged in a crossed attitude in relation to the polarizer 3. The internal faces of the plates 4 and 5 are equipped with transparent electrodes connected to an electrical generator 9. The light, on having passed through the aforescribed assembly, can be received, directly by the eye of the observer located in the neighbourhood of Oz, or projected by the lens 8 upon a diffuser screen, not shown in the figure. The elements 3, 30, 4, 6, 5, 70 and 7, are arranged perpendicularly to the axis Oz.

This device differs, therefore, from the device shown in Fig. 1 of the Parent Patent, by the addition of the two quarterwave plates 30 and 70, whose principal directions are arranged at 45° to the directions of polarization of polarizer 3 and analyser 7, these latter being assumed to be respectively parallel to the directions \vec{OX} and \vec{OY} .

Those skilled in the art will appreciate that a nematic liquid crystal, constituted by elongated molecules orientated parallel to their common lengthwise direction \vec{D} , constitutes a uniaxial double-refracting medium, the optical axis of which is parallel to the direction \vec{D} . If, at the time of manufacture of the cell, it is arranged that said direction \vec{D} differs from the direction \vec{Oz} , then in the absence of any supplied field the cell will exhibit a certain double-refraction effect which will be maximum if \vec{D} is parallel to the plane of the plates 4 and 5. By applying a voltage to the electrodes, an electric field parallel to \vec{Oz} is produced which causes the nematic molecules, these being highly polarizable, to rotate in the plane defined by the two directions \vec{D} and \vec{Oz} ; the direction \vec{D} thus rotates through an angle \hat{A} which is the greater the stronger the field. The principal directions, constituted by the projection of \vec{D} on to the plane OXY and by the perpendicular to this projection, do not vary, but the phase difference, introduced by the plate, between the two preferred optical vibrations parallel to these principal directions, is modified. In this case, the device described by Fig. 1 of the Parent Patent, operates satisfactorily: The polarizer 3 furnishes a linearly polarized wave, the thin film 6 transforms it into elliptical vibration, and the analyser 7, crossing the polarizer 3, transmits a light intensity which depends both upon the relative

orientations of the polarizer 3, the analyzer 7 and the principal directions of the film, and upon the degree of double refraction in the film.

5 This situation changes if, by construction, the common direction \vec{D} of alignment of the molecules, is arranged parallel to OZ, and therefore perpendicular to the plates, something which can be achieved, for example, by
10 doping the liquid crystal with an appropriate surface-acting agent. Under zero field, the thin film behaves like an isotropic plate. When the field is applied, parallel to OZ, all the molecules rotate through the same angle \hat{A}
15 about an axis of rotation perpendicular to OZ; however, because of the axial symmetry of the system, this axis of rotation has no preferential direction and the direction can in fact be any arbitrary direction in the plane XOY; also, the thin film splits up into domains, each characterised by a peculiar direction of the said axis of rotation; the
20 common direction \vec{D} of lengthwise extent of the molecules belonging to each domain, are then randomly distribution on a cone of axis \vec{OZ} whose apex half angle is \hat{A} . The direction of the principal directions varies, therefore, from one domain to another, but the phase difference, produced between the two preferred vibrations parallel to these principal directions remains constant over the whole of the
30 surface of the thin film since it is a function solely of the value of the angle \hat{A} . Under these conditions, examination between cross polarizers results in the appearance, between
35 the different domains, of differences of light intensity (when using monochromatic light) or colour (white light), due to the different orientations of their principal directions in relation to the plane of polarization of the incident light.

The modification in accordance with the preferred embodiment of Figure 1, consisting in the introduction of two quarterwave plates at
45 either side of the thin film, makes it possible to overcome this difficulty and to re-establish uniformity of the light intensity at the output of the analyzer. The quarterwave plate 30, which receives the linearly polarized incident wave leaving the polarizer 3, at 45° to its
50 principal directions, converts this wave into a circularly polarized wave with a propagation axis \vec{OZ} . Thus, there is coincidence between the symmetry of the lightwave incident upon the thin film, and that imposed by the electric field upon the different constituent molecules of the film; by compensating for the path difference introduced by the quarterwave plate 30, using a second quarterwave plate 70, the
55 influence of the differing principal directions is eliminated. The calculation which now follows, confirms this analysis.

Let us consider a linearly polarized wave propagating in the direction of \vec{OZ} , of amplitude a and radiant frequency ω , and oscillating
65 in the direction \vec{OX} . Said direction \vec{OX} is the bisector of the two directions OX_1 , OY_1 , shown in fig. 2 and corresponding to the two principal directions of the quarterwave plate 30. Thus, at the input of a given domain of the nematic thin film 6, there is a circularly polarized wave described by the equations:

$$X_1 = \frac{a\sqrt{2}}{2} \sin \omega t$$

$$Y_1 = \frac{a\sqrt{2}}{2} \cos \omega t$$

If OX_2 , OY_2 are used to designate the principal directions of this domain and by calling α the angle (OX_1, OX_2) , the equations of the incident circular vibration can be written, in relation to the directions OX_2 , OY_2 , as:

$$X_2 = \frac{a\sqrt{2}}{2} \sin(\omega t + \alpha)$$

$$Y_2 = \frac{a\sqrt{2}}{2} \cos(\omega t + \alpha)$$

On traversing the thin film, the wave propagating in accordance with OY_2 is delayed by φ in relation to the wave propagating in accordance with OX_2 ; the equations for the components of the emergent wave are thus:

$$X_2 = \frac{a\sqrt{2}}{2} \sin(\omega t + \alpha)$$

$$Y_2 = \frac{a\sqrt{2}}{2} \cos(\omega t + \alpha - \varphi)$$

The principal directions of the second quarterwave plate 70 are likewise directed
90 along \vec{OX}_1 and \vec{OY}_1 . Considered in relation to these principal directions, the two components corresponding to the wave which has passed through the domain in question, have the following equations:

$$X_1 = \frac{a\sqrt{2}}{2} [\sin(\omega t + \alpha)$$

$$\cos \alpha - \cos(\omega t + \alpha - \varphi) \sin \alpha]$$

$$Y_1 = \frac{a\sqrt{2}}{2} [\sin(\omega t + \alpha)]$$

$$\sin \alpha + \cos(\omega t + \alpha - \varphi) \cos \alpha]$$

- 5 The equations of the two preferred vibrations, after passing the plate 70 and assuming that the direction \vec{OY}_1 has a phase lead of

$$\frac{\pi}{2}$$

in relation to the Direction \vec{OX}_1 , become:

$$X_1 = \frac{a\sqrt{2}}{2} [\sin(\omega t + \alpha)]$$

$$\cos \alpha - \cos(\omega t + \alpha - \varphi) \sin \alpha]$$

$$10 \quad Y_1 = \frac{a\sqrt{2}}{2} [\cos(\omega t + \alpha)]$$

$$\sin \alpha - \sin(\omega t + \alpha - \varphi) \cos \alpha]$$

- 15 These two vibrations combine in the direction \vec{OY} of the rectilinear vibration transmitted by the analyser 7, to give linearly polarized wave whose equation is:

$$Y = \frac{\sqrt{2}}{2} (Y_1 - XX_1)$$

$$= \frac{a}{2} [\sin(\omega t + 2\alpha) + \sin(\omega t + 2\alpha - \varphi)]$$

equation which can be written:

$$Y = a \cos \frac{\varphi}{2} \cdot \sin(\omega t + 2\alpha - \frac{\varphi}{2})$$

- 20 The intensity of the light wave of the output from the analyser, the value of which is

$$(a \cos \frac{\varphi}{2})^2,$$

- 25 is therefore independent of the value of α which characterises the orientation of the principal directions in relation to each domain, and depends only upon the value of φ , characteristic of the phase difference and uniform at all points, introduced by the thin film.
If, in accordance with an embodiment des-

cribed in the Parent Patent, one of the transparent electrodes deposited upon the plates 4 or 5, instead of covering the whole surface of the plate, covers only part of it and is given the form of a graphic symbol it is desired to display, then the modification proposed in accordance with the addition and described just previously, makes it possible to display this symbol:

— as a dark symbol against a light background when using monochromatic illumination;
— as a coloured symbol against a background of different colour when using white light.

Indeed, the light intensity transmitted by the analyser varies in accordance with

$$\cos \frac{\varphi}{2};$$

the result is that when using monochromatic illumination, it is a maximum in those regions of the cell located outside the electrodes and therefore not subjected to the applied field.

It is therefore often more interesting to replace one of the quarterwave plates 30 or 70 by a three-quarterwave plate. A calculation very similar to the preceding one, shows that then the intensity of the light transmitted by the analyser varies in accordance with a

$$\sin \frac{\varphi}{2}$$

law. The graphic symbol to be displayed then appears against a dark background.

It goes without saying that what has been said hereinbefore continues to apply if the quarterwave or three-quarter wave plates are replaced by plates which produce between the two preferred vibrations, a differential phase shift satisfying the general formula

$$(2k+1) \frac{\pi}{2}$$

It is likewise possible, in accordance with a variant embodiment of the present addition, to replace the two transparent plates 4 and 5 enclosing the thin film of nematic liquid crystal 6 by two plates of quarterwave, three-quarterwave kind etc. etc., having their principal directions at 45° to the directions of polarization of polarizer and analyser.

In the case where the source 1 emits polychromatic light, the characteristic wavelength of the quarterwave, three-quarterwave or other plates, will be chosen as the mean wavelength of the emitted radiation.

Fig. 3 and 4 relate to the second solution proposed according to the present invention, which solution consists in imposing upon the

molecules, initially orientated perpendicularly to the planes of the plates enclosing the thin film, a single axis of rotation when the electric field is applied.

In Fig. 3, the internal face, in contact with the nematic crystal film, of one of the plates 4 or 5 of Fig. 1 can be seen. In this face, extremely shallow scratches such as those 400, parallel with one another and in this case arranged at 45° to the directions \vec{OX} and \vec{OY} , are produced. These scratches are produced by rubbing the plates using the so-called Chatelain technique. This technique is generally utilised to produce in the plate scratches which, as stated in the Parent Patent, make it possible to achieve common orientation of the long molecules parallel to the plates, the axes of the molecules therefore being parallel to the scratches. In the context of the present addition, this rubbing operation is sufficiently gentle not to disturb the orientation perpendicular to the plates, achieved by virtue of the influence of the surface-active agent. The scratches only come into play at the time of application of the electric field, to dictate the direction of the axis of rotation of the molecules; the latter is thus disposed perpendicularly to the scratches. This thus prevents the formation in the body of the thin film, of domains characterised by differences in the orientations of their principal directions. Thanks to this method, the thin film has a single orientation of principal directions, one of them, corresponding to the projection of the optical axis upon the plane of the plate, being parallel to the direction of the scratches.

It goes without saying that the scratched part of the plate is that in direct contact with the nematic crystal; this part can therefore be the electrode deposited at the surface of plate or, as described in the Parent Patent, the transparent dielectric film inserted between the liquid crystal and an electrode to inhibit the conduction current in the film 6.

It is equally possible to scratch the two surfaces which are in contact with the opposite faces of the thin film. In this case, it will be arranged that the scratches in the two faces are parallel to a common direction.

Fig. 4 pertains to a variant embodiment of this solution, which consists in giving the nematic molecule a preferential direction of rotation; in accordance with this variant, the direction is imposed by an additional electric field parallel to the plane of the plates.

This figure represents a cell constituted by the thin film 6 of nematic crystal, arranged between two transparent plates 4 and 5 upon which the two main electrodes 40 and 50 are deposited, these being connected to the electrical generator 9. Between the two plates 4 and 5 there are arranged two spacers 45 and 54, coated upon their external faces with two additional electrodes 450 and 540, each of these

being connected to a second electrical generator 90.

The two additional electrodes create inside the film 6 an additional electric field the direction of which is parallel to the plane of the plates and which, therefore, in the absence of any voltage on the main electrodes, is perpendicular to the common direction D of orientation of molecules. Consequently, the couple exerted by this additional field on molecules is zero. By contrast, as soon as a field is applied through the medium of the main electrodes, the field created by the additional electrodes exerts a tangible couple which gives the molecules a uniform axis of rotation perpendicular to the direction of the associated field.

It is also in accordance with the second solution described in the present invention and consisting in imposing upon the molecules a single rotation axis orientation when the electric field is applied, to replace the above mentioned additional electric field by a magnetic field.

WHAT WE CLAIM IS:—

1. An electrically controlled modulator as claimed in claim 1 of the Parent Patent Application No. 37 172/71 (Specification No. 1,364,274), wherein said molecular alignment is perpendicular to said plates, said control means comprising transparent electrodes arranged respectively upon the internal faces of said plates and said variable electric signal being a variable voltage applied between said electrodes;

and further comprising first and second optical means for respectively transforming linearly polarized light into circularly polarized light and circularly polarized light into linearly polarized light, said first and second optical means being arranged between said plane polarizers respectively at either side of said film.

2. An electrically controlled modulator as claimed in claim 1, wherein said first and second optical means are constituted by two parallel double-refracting plates whose principal directions are arranged at 45° to the directions of polarization of said polarizers, each of said two double-refracting plates, creating, between the two preferred vibrations parallel to its principal directions, a path difference equal to q quarter-wavelengths of said lightbeams, q being an odd whole number.

3. An electrically controlled modulator as claimed in claim 2, wherein said two parallel double-refracting plates constitute said pair of evenly spaced transparent plates.

4. An electrically controlled modulator as claimed in claim 1 of the Parent Patent Application No. 37 172/71 (Specification No. 1,364,274), wherein said molecular alignment is perpendicular to said plates, said control means comprising transparent electrodes arranged respectively upon the internal faces of said

plates and said variable electric signal being a variable voltage applied between said electrodes;

5 said film of a liquid crystal exhibiting a nematic phase is in contact with at least one surface containing parallel scratches, said scratches imposing, upon application of said variable voltage between said electrodes, a single direction to the rotation axis of said molecules.

10 5. An electrically controlled modulator as claimed in claim 1 of the Parent Patent Application No. 37 172/71 (Specification No. 1,364,274), wherein said molecular alignment is perpendicular to said plates, said control means comprising transparent electrodes arranged respectively upon the internal faces of said plates and said variable electric signal being a variable voltage applied between said electrodes;

20 and further comprising electrical means for creating an additional electric field within the body of said film at least within the time interval during which said variable voltage is applied, said additional electric field being dis-

posed parallel to the plane of said film.

6. An electrically controlled modulator as claimed in claim 5, wherein said electrical means comprise two insulating spacers enclosing said thin film and disposed in a parallel arrangement between said transparent plates, additional conductive electrodes arranged on the external faces of each of said spacers, and generator means for applying a voltage across said electrodes.

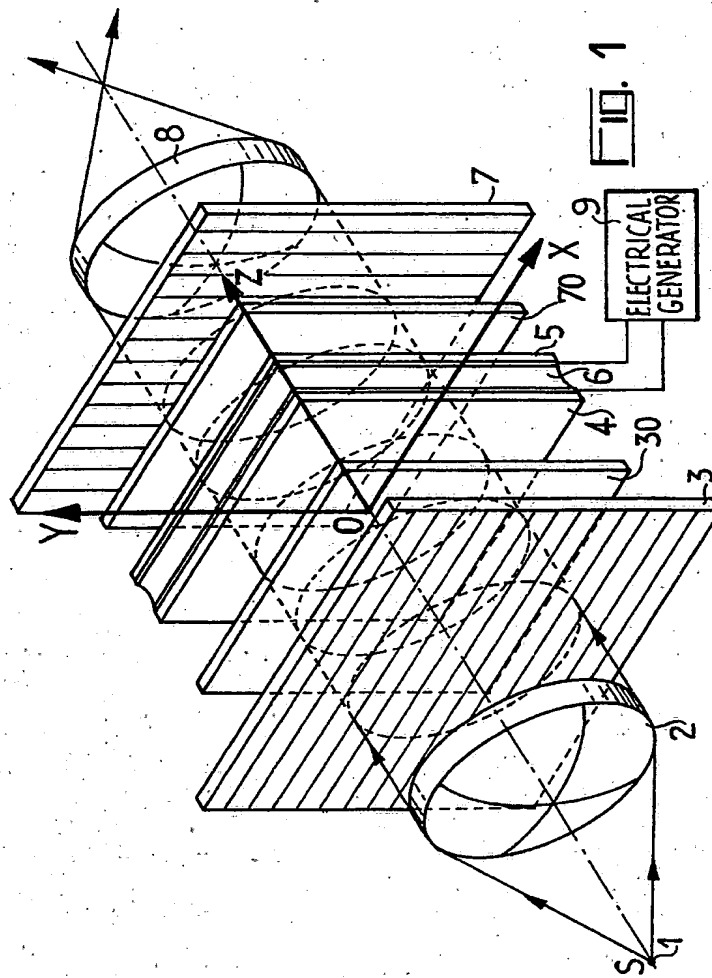
7. An electrically controlled modulator substantially as hereinbefore described with reference to the accompanying drawings.

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Sheet 2

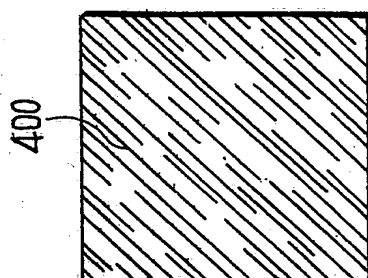


FIG. 3

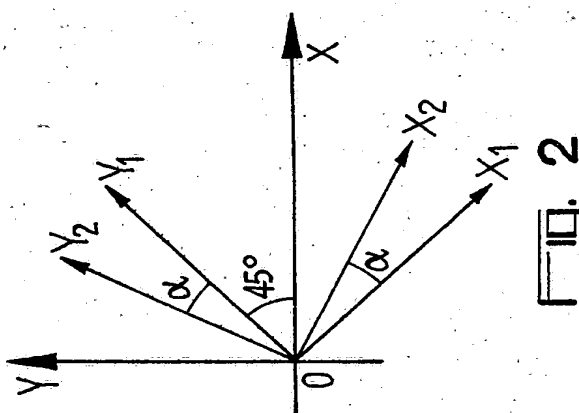


FIG. 2

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Sheet 3

